sound to travel from transducer **110** to transducer **112**. In the FIG. **3** embodiment, a single transducer **114** is arranged relative to a surface **116** in pulse-echo mode for measuring the time it takes sound to travel from transducer **114** to surface **116** and back. Because the ultrasound travels through the fluid in a time-of-flight measurement, it is preferred to use a lower frequency of ultrasound in the time-of-flight measurement than in the echo measurement to minimize attenuation of ultrasound in the fluid during the time-of-flight measurement. In particular forms, the time-of-flight measurement is performed at a frequency below about 1 MHz

One variation of system **20** is depicted in FIG. **4**. System **24** includes both a shear wave transducer **34** and a longitudinal wave transducer **36**. Transducers **34** and **36** are each coupled to pulser **50** and processing apparatus **22** via a multiplexer **38**. In this variation, processing apparatus **22** is programmed to simultaneously or sequentially cause shear waves and longitudinal waves to be reflected through member **40**. Processing apparatus **22** is programmed to receive the output of longitudinal transducers **34** when longitudinal waves are being reflected through member **40** and to determine fluid density information as described above with respect to system **20**. Alternatively, longitudinal wave transducer **34** can be omitted with fluid density determined by any other means known in the art.

Processing apparatus **22** is also programmed to determine one or more additional properties of the fluid utilizing the response of transducer **36** to the reflected shear waves in combination with the determined density information. The response from shear transducer **36** is process as described above with respect to transducer **30** to calculate the acoustic impedance of the fluid according to equations (1)–(3), where the values used in equation (1)–(3) and the determined acoustic impedance (Zfluid) appropriately correspond to values for shear waves.

In one preferred form, the additional properties determined from the shear wave acoustic impedance depend on the properties of the fluid being interrogated. The propagation of a shear waves in liquids is described in J. Blitz, Fundamentals of Ultrasonics, 2nd Edition, Plenum Press, New York, 1967, pp.130–134, which is hereby incorporated by reference in its entirety. As described in Blitz, both the viscosity (η) and the shear modulus (G) are parameters in differential equations involving the rate of change of the shear strain, the pressure, and the pressure time dependence for shear wave propagation. The relaxation time (τ) for liquids is defined as the viscosity (η) divided by the shear modulus (G). Where the relaxation time is small such that the terms involving G can be ignored, the viscosity of the fluid (η) is calculated in accordance with equation (5).

$$Zfluid=(\omega\rho_F\eta/2)^{0.5} \tag{5}$$

where ω is the radial frequency of the shear wave and ρ_F is the determined fluid density. Exemplary small relaxation times for this form include relaxation times less than about 10^{-9} and more preferably on the order of about 10^{-12}. An equivalent formulation for determining fluid viscosity by combining equations (3) and (5) and substituting for Zsolid is given in equation (5a).

$$(\rho_F\eta)^{0.5}=\rho s c_{TS}\left(\frac{2}{\omega}\right)^{0.5}\left(\frac{1-RCfluid}{1+RCfluid}\right) \tag{5a}$$

where ρs is the density of the solid and c_{TS} is the shear wave velocity in the solid.

For fluids **25** where the value of ωτ>>1, shear modulus (G) or the shear velocity in the fluid (c_{tf}) can be calculated according to equations (6) and (7).

$$Zfluid=(\rho_F G)^{0.5} \tag{6}$$

$$Zfluid=(\rho_F c_{tf}) \tag{7}$$

Exemplary values for ωτ according to this form include values greater than about 3 and more preferably greater than about 11.

In other forms or where these simplifications are not utilized, additional fluid properties can be determined by solving Blitz's differential equations numerically and/or by any means known in the art.

Transducers useful for forming and receiving the ultrasound pulse echo series in practicing the present invention can operate in the range of about 0.5 to 20 MHz, more preferable between about 1 and 10 MHz, and most preferably about 5 MHz. In certain applications of the invention, the thickness T of member **40** will be predetermined, and depending on the wavelength of ultrasound in the member **40**, the ratio of thickness T to wavelength could be significant, for example greater than about 0.05. As one example, it is contemplated that member **40** would be the existing wall of a stainless steel pipe or container about 0.15 inches thick. For at least some selected ultrasonic frequencies, the wavelength of ultrasound will be significant relative to the wall thickness.

Where the length of the pulse in the member **40** is a concern, a broadband ultrasound pulse can be used. Pulser **50** inputs a square wave or spike input to transducer **30**, where the non-sinusoidal input has a duration less than the time it takes the transducer to perform a half cycle at the transducer center frequency (give by the inverse of the frequency of the transducer). The transducer **30** responds to this short input stimulus by emitting an ultrasonic pulse into member **40** of short duration, for example on the order of about 3–4 wavelengths in length. In this manner, the length of the ultrasound pulse in member **40** can be minimized and the echoes detected by transducer **30** can be readily resolved, because the potential for overlap is typically reduced.

In another form of the invention, because of the materials desired for solid member **40** and fluid **25**, the acoustic impedance ratio Zsolid/Zfluid will be significant, for example, greater than about 5 or 10. In this form, the ultrasound pulse is preferably detected as it undergoes a large number of reflections between surfaces **42** and **44** of member **40**, for example more than about 10 reflections, preferably about 15–20 reflections. The multiple reflections serve to amplify the effect of small changes in properties of fluid **25**. This amplification occurs because the amplitude of the pulse is diminished in accordance with the reflection coefficient (RCfluid) with each successive reflection with surface **44**. Also, because the higher echoes undergo more reflections with surface **44** and because the reflection coefficient (RCfluid) is a function of fluid properties, the effect of changes in these fluid properties are more pronounced in the higher echo numbers. Consequently, in one form of the invention, it is preferred that at least some of the higher number echoes are used in computing the decay rate.

In further forms of the invention, where reduction of the adverse effects of divergence and/or attenuation is of concern, selection of transducer **30** and member **40** dimensions and properties can be of particular interest. For example, the near field can be considered the region immediately in front of an ultrasonic transducer where the sound beam is does not diverge and signal loss is at a minimum. The near field length (Nf) for an ultrasonic transducer can be approximated by equation (8)

$$Nf=0.25D^2/lambda \tag{8}$$

where lambda is the wavelength of the ultrasound in the medium (equal to local speed of sound divided by the